3.7.2 Decision Errors for Elevated Areas

When the concern is to test the average residual radioactivity concentration, the actual surface area of the survey unit is immaterial except insofar as it should be consistent with that assumed in the dose pathway model used. It is only the distribution of the measured concentrations in the survey unit, its mean and its variance that are important. When the concern is finding isolated areas of elevated activity, the size of the survey unit must be explicitly taken into account. This is because the probability of discovering an elevated area depends on the sampling density, i.e., the distance between sampling locations.

From Section 3.5.4, the length (or spacing), L, of the systematic pattern is given by:

$$L = \sqrt{\frac{A}{0.866\ n}} \quad \textit{for a triangular grid}$$

and

$$L = \sqrt{\frac{A}{n}} \quad \textit{for a square grid}$$

where A is the area of the survey unit.

A computer code for determining the probability that an elliptically shaped elevated area would be missed by a systematic sampling grid was developed by Singer (1972). An elliptical area can be described by the length Λ, of its semi-major axis and its shape (the ratio of major and minor axis lengths), S. For a circle the length is simply the radius and the shape, S, is one. Figure 3.6 shows an example of a circular (S = 1.0) area with radius L/2 and an elliptical (S = 0.2) area with semi-major axis length L, compared to both square and triangular sampling grids with spacing L.

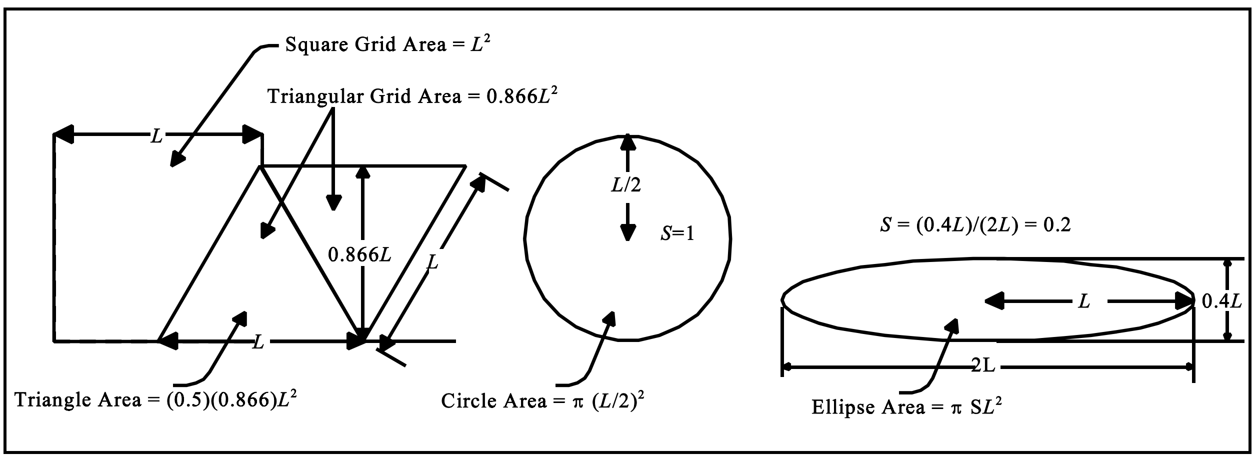

Figure 3.6 Circular and Elliptical Areas Relative to the Sample Grid

Singer's computer code, ELIPGRID, has been improved and modified for use on personal computers by Davidson (see ORNL/TM-12774). This code, ELIPGRID-PC, was used to generate the data for Figure 3.7.

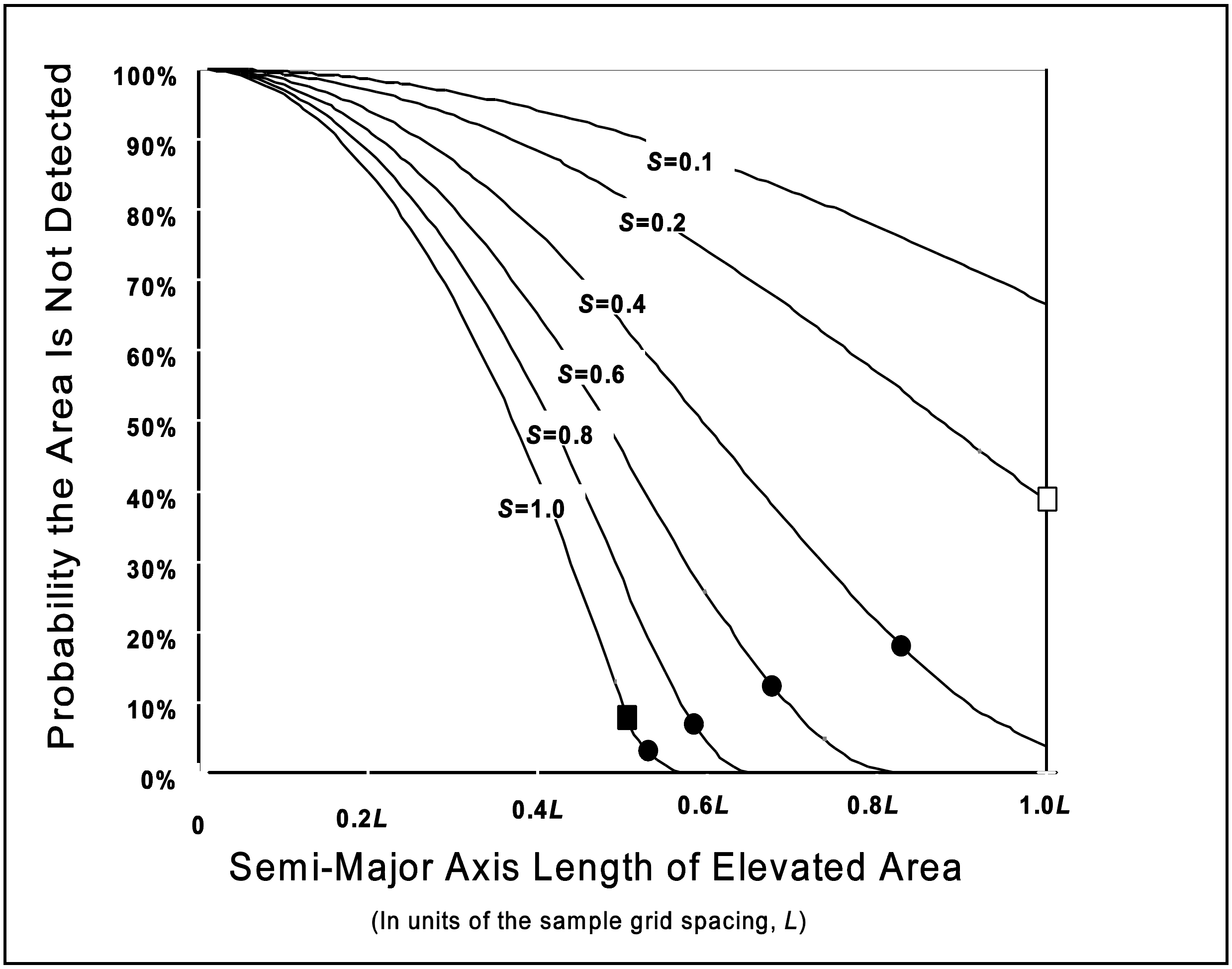

Figure 3.7 Probability an Elliptical Area Is Not Sampled on a Triangular Grid

This figure shows the probability that an elevated area of a given size and shape is not detected using a triangular sampling grid with spacing L. Note that the area of an ellipse of length Λ is $\pi S\Lambda^2$, so that for a given value of, an ellipse of length Λ with shape $S = 0.2$ has only one-fifth the area of a circle ($S = 1.0$) of the same length, i.e., radius. That is one reason, in addition to the area becoming longer and thinner, that the probabilities increase as S decreases.

The black and white squares in Figure 3.7 correspond the circle ($S = 1.0$, $\Lambda = 0.5L$) and the ellipse ($S = 0.2$, $\Lambda = L$) shown in Figure 3.6. The probability is less than 10% that the circle would go undetected. The probability is about 40 percent that the ellipse would go undetected, even though its area ($0.628\ L^2$) is only slightly smaller than the area of the circle ($0.785\ L^2$).

The circles in Figure 3.7 correspond to elevated areas equal to the triangular grid area, $0.866L^2$. The probability of missing them is rather low unless the shape parameter is also very low.

In Figure 3.8, the probabilities of missing a circular elevated area with triangular and square systematic grids are compared. The square grid is only slightly less efficient than the triangular grid. It can be concluded that, in most cases, an elevated area of the same size as, or larger than, that defined by the sampling grid is likely to be discovered during the final status survey.

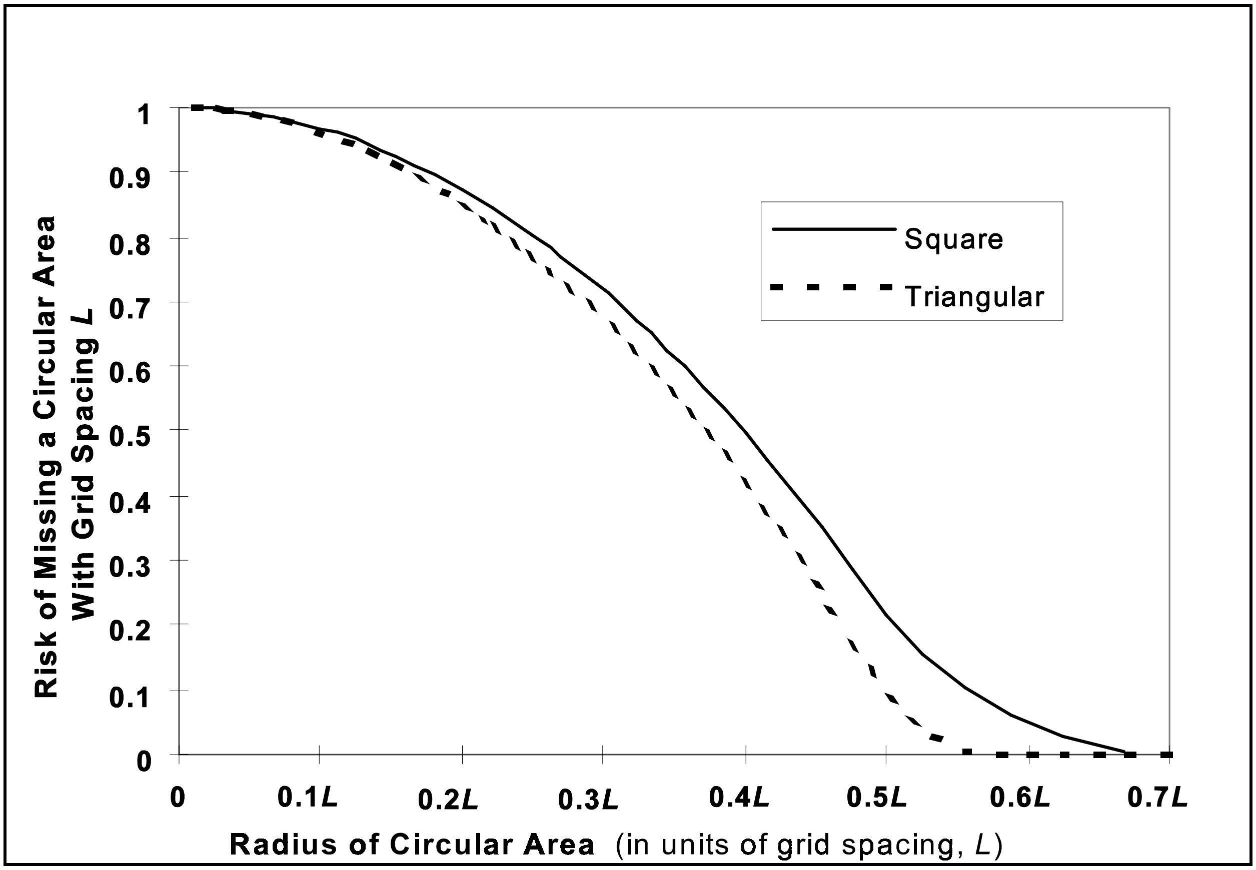

Figure 3.8 Probability a Circular Area Is Not Sampled on a Systematic Grid

3.8 Optimize the Design

The DQO process need be neither static nor sequential. Some of the activities involved may be taking place concurrently, and may be visited more than once. At any stage in the process, new information may be available that should then be incorporated into planning the final status surveys.

Optimization of the final status survey involves examining all of the factors that effect the decision errors and sample sizes so that costs and potential risks are balanced. The primary factors to be considered in optimizing the design for determining the mean concentration are the $DCGL_W$ and the measurement standard deviation. The estimate of the measurement standard deviation should include both the uncertainty in measurement process and any anticipated spatial and temporal concentration variations. The delineation and classification of survey units and reference areas can affect the spatial variability. Scan sensitivity is a primary consideration in optimizing the design to ensure no elevated areas remain in a survey unit. The Area Factor and the scan MDC are the important parameters which can impact survey costs and uncertainty.

3.8.1 Optimizing the Design for the Mean Concentration

There are relationships between the measurement uncertainty, σ, the width of the gray region, Δ, the desired decision error limits (α and β) and the number of measurements needed to meet those limits. This is illustrated in Table 3.2 for the case when no reference area is needed (one-sample test). Table 3.3 is used when the survey unit is compared to a reference area (two-sample test), and lists the number of samples to be taken in each. The method used to generate these tables is discussed in Chapter 9.

Table 3.2 Number of Samples, *N*, Required in Survey Unit to Meet Error Rates α, and β, With Relative Shift Δ/σ, When Using the Sign Test

	α = 0.01				α = 0.05				α = 0.10				α = 0.25			
	β				β				β				β			
Δ/σ	0.01	0.05	0.10	0.25	0.01	0.05	0.10	0.25	0.01	0.05	0.10	0.25	0.01	0.05	0.10	0.25
0.1	4095	2984	2463	1704	2984	2048	1620	1018	2463	1620	1244	725	1704	1018	725	345
0.2	1035	754	623	431	754	518	410	258	623	410	315	184	431	258	184	88
0.3	468	341	282	195	341	234	185	117	282	185	143	83	195	117	83	40
0.4	270	197	162	113	197	136	107	68	162	107	82	48	113	68	48	23
0.5	178	130	107	75	130	89	71	45	107	71	54	33	75	45	33	16
0.6	129	94	77	54	94	65	52	33	77	52	40	23	54	33	23	11
0.7	99	72	59	41	72	50	40	26	59	40	30	18	41	26	18	9
0.8	80	58	48	34	58	40	32	21	48	32	24	15	34	21	15	8
0.9	66	48	40	28	48	34	27	17	40	27	21	12	28	17	12	6
1.0	57	41	34	24	41	29	23	15	34	23	18	11	24	15	11	5
1.1	50	36	30	21	36	26	21	14	30	21	16	10	21	14	10	5
1.2	45	33	27	20	33	23	18	12	27	18	15	9	20	12	9	5
1.3	41	30	26	17	30	21	17	11	26	17	14	8	17	11	8	4
1.4	38	28	23	16	28	20	16	10	23	16	12	8	16	10	8	4
1.5	35	27	22	15	27	18	15	10	22	15	11	8	15	10	8	4
1.6	34	24	21	15	24	17	14	9	21	14	11	6	15	9	6	4
1.7	33	24	20	14	24	17	14	9	20	14	10	6	14	9	6	4
1.8	32	23	20	14	23	16	12	9	20	12	10	6	14	9	6	4
1.9	30	22	18	14	22	16	12	9	18	12	10	6	14	9	6	4
2.0	29	22	18	12	22	15	12	8	18	12	10	6	12	8	6	3
2.5	28	21	17	12	21	15	11	8	17	11	9	5	12	8	5	3
3.0	27	20	17	12	20	14	11	8	17	11	9	5	12	8	5	3

Table 3.3 Number of Samples, *N*/2, Required in Both Reference Area and Survey Unit to Meet Error Rates α and β With Relative Shift Δ/σ, When Using the Wilcoxon Rank Sum Test

	α = 0.01				α = 0.05				α = 0.10				α = 0.25			
	β				β				β				β			
Δ/σ	**0.01**	**0.05**	**0.10**	**0.25**	**0.01**	**0.05**	**0.10**	**0.25**	**0.01**	**0.05**	**0.10**	**0.25**	**0.01**	**0.05**	**0.10**	**0.25**
0.1	5452	3972	3278	2268	3972	2726	2157	1355	3278	2157	1655	964	2268	1355	964	459
0.2	1370	998	824	570	998	685	542	341	824	542	416	243	570	341	243	116
0.3	614	448	370	256	448	307	243	153	370	243	187	109	256	153	109	52
0.4	350	255	211	146	255	175	139	87	211	139	106	62	146	87	62	30
0.5	227	166	137	95	166	114	90	57	137	90	69	41	95	57	41	20
0.6	161	117	97	67	117	81	64	40	97	64	49	29	67	40	29	14
0.7	121	88	73	51	88	61	48	30	73	48	37	22	51	30	22	11
0.8	95	69	57	40	69	48	38	24	57	38	29	17	40	24	17	8
0.9	77	56	47	32	56	39	31	20	47	31	24	14	32	20	14	7
1.0	64	47	39	27	47	32	26	16	39	26	20	12	27	16	12	6
1.1	55	40	33	23	40	28	22	14	33	22	17	10	23	14	10	5
1.2	48	35	29	20	35	24	19	12	29	19	15	9	20	12	9	4
1.3	43	31	26	18	31	22	17	11	26	17	13	8	18	11	8	4
1.4	38	28	23	16	28	19	15	10	23	15	12	7	16	10	7	4
1.5	35	25	21	15	25	18	14	9	21	14	11	7	15	9	7	3
1.6	32	23	19	14	23	16	13	8	19	13	10	6	14	8	6	3
1.7	30	22	18	13	22	15	12	8	18	12	9	6	13	8	6	3
1.8	28	20	17	12	20	14	11	7	17	11	9	5	12	7	5	3
1.9	26	19	16	11	19	13	11	7	16	11	8	5	11	7	5	3
2.0	25	18	15	11	18	13	10	7	15	10	8	5	11	7	5	3
2.25	22	16	14	10	16	11	9	6	14	9	7	4	10	6	4	2
2.5	21	15	13	9	15	11	9	6	13	9	7	4	9	6	4	2
2.75	20	15	12	9	15	10	8	5	12	8	6	4	9	5	4	2
3.0	19	14	12	8	14	10	8	5	12	8	6	4	8	5	4	2
3.5	18	13	11	8	13	9	8	5	11	8	6	4	8	5	4	2
4.0	18	13	11	8	13	9	7	5	11	7	6	4	8	5	4	2

The width of the gray region, Δ, is a parameter that is central to the nonparametric tests discussed in this report. It is also referred to as the *shift.* In this report, the gray region is always bounded from above by the $DCGL_W$ corresponding to the release criterion. The *Lower Boundary of the*

Gray Region (LBGR) is selected during the DQO process along with the target values for α and β, as discussed in Section 3.7.1. The width of the gray region, or shift, Δ, is equal to (DCGL − LBGR). The absolute size of the shift is actually of less importance than the *relative shift* Δ/σ, where σ is an estimate of the standard deviation of the measured values in the survey unit. The estimated standard deviation, σ, includes both the real spatial variability in the quantity being measured, and the precision of the chosen measurement method. The relative shift, Δ/σ, is an expression of the resolution of the measurements in units of measurement uncertainty. Expressed in this way, it is easy to see that relative shifts of less than one standard deviation, $\Delta/\sigma < 1$, will be difficult to detect. On the other hand, relative shifts of more than three standard deviations, $\Delta/\sigma > 3$, are generally easy to detect.

It is evident from Tables 3.2 and 3.3, that the number of measurements that will be required to achieve given error rates (α and β) depends entirely on the value of Δ/σ. Note also that the number of measurements required is symmetric in α and β. For example, if $\Delta/\sigma = 1$, $\alpha = 0.05$ and $\beta = 0.10$, then, from Table 3.1, the number of samples needed for the Sign test is 23. For the same value of Δ/σ, but with error rates reversed (i.e., $\alpha = 0.10$ and $\beta = 0.05$), the number of samples needed for the Sign test is again 23. Thus, these tables may be used to plan the number of measurements needed, regardless of whether Scenario A or Scenario B is used. It is only when the statistical test is *actually performed* on the measurement results that the distinction between α and β becomes important.

For fixed values of α and β, small values of Δ/σ result in large numbers of samples. It is desirable to design for $\Delta/\sigma > 1$ whenever possible. There are two obvious ways to increase Δ/σ. The first is to increase the width of the gray region by making LBGR small. The disadvantage is that the acceptable probability of the survey unit passing will be specified at this smaller LBGR. Thus, a survey unit will generally have to be lower in residual radioactivity to have a high probability of being judged to meet the release criterion. The second way to increase Δ/σ is to make σ smaller. One way to make σ small is by having survey units that are relatively homogeneous in the amount of measured radioactivity. This is an important consideration in selecting survey units that have both relatively uniform levels of residual radioactivity and also have relatively uniform background radiation levels. Measurements performed during scoping, characterization, and remedial action support surveys can be useful for determining an estimate of σ for the final status survey planning.

Another way to make σ small is by using more precise measurement methods. The more precise methods might be more expensive, but this may be compensated for by the decrease in the number of required measurements. One example would be in using a radionuclide specific method rather than gross radioactivity measurements for residual radioactivity that does not appear in background. This would eliminate the variability in background from σ, and would also eliminate the need for reference area measurements. On the other hand, the costs associated with performing additional measurements with an inexpensive measurement system may be less than the costs associated with fewer measurements of higher precision.

The effect of changing the width of the gray region and/or changing the measurement variability on the estimated number of measurements (and cost) can be investigated using Table 3.1 and 3.2. Generally, the design goal should be to achieve Δ/σ values between one and three. The number of samples needed rises dramatically when Δ/σ is smaller than one. Conversely, little is usually gained by making Δ/σ larger than about three. If Δ/σ is greater than three or four, one can take advantage of the measurement precision available by making the width of the gray region smaller. It is even more important, however, that overly optimistic estimates for σ be avoided. The consequence of taking fewer samples than are needed given the actual measurement variations will be increased error rates, leading to either unnecessary remediations (Scenario A) or improper survey unit release (Scenario B).

On the other hand, a smaller number of samples may still result in acceptable error rates. When Δ/σ is small, and the number of samples is large, a modest increase in the acceptable error rates may result significant reduction in the number of samples required. Given the other uncertainties involved, the cost savings may justify larger acceptable error rates. The advantage of the optimization step of the DQO process is that several alternatives can be explored on paper before time and resources are committed.

One consideration in setting the error rates are the health risks associated with releasing a survey unit that might actually contain residual radioactivity in excess of the DCGL. If a survey unit did exceed the DCGL, the first question that arises is "How much above the DCGL is the residual radioactivity likely to be?" Figures 3.9 through 3.12 can be used to estimate this.

These figures show the probability of the survey unit passing the statistical tests as a function of the true concentration of residual radioactivity in the survey unit. Figures 3.9 and 3.10 are for the one-sample Sign test, under Scenario A and B, respectively. Figures 3.11 and 3.12 are for the two-sample WRS test, under Scenario A and B, respectively. In these figures, the black-colored curves are those for $\alpha = 0.01$, the white-colored curves are those for $\alpha = 0.10$, and the gray-colored curves are those for $\alpha = 0.25$. For each value of α, survey unit sample sizes of 10, 15, 20, 30, 50 and 100 are shown. Note that in Scenario A, α is the probability that the survey unit passes when the concentration is equal to the $DCGL_W$. In Scenario B, α is the probability that the survey unit passes when the concentration is equal to the LBGR.

For example, if the $DCGL_W$ is 1.0, the LBGR is 0.5, σ is 1.0, $\alpha = 0.05$ and $\beta = 0.05$, then $\Delta/\sigma = 0.5$ and Table 3.2 indicates that 89 samples would be required. If $\alpha = 0.1$ and $\beta = 0.1$, then only 54 samples are required. How likely is it that a survey unit with residual radioactivity 50% higher than the $DCGL_W$ would pass? A concentration 50% higher than the $DCGL_W$ is 1.5, which is the same as the $DCGL_W + 0.5\sigma$. For the Sign test in Scenario A, Figure 3.9 (second white curve from the left) shows that the probability of the survey unit passing is near zero for a concentration of 1.5 when $\alpha = 0.1$ and the sample size is 50. While a survey unit with residual radioactivity equal to the $DCGL_W$ might have a 10% chance of being released, a survey unit at the $DCGL_W + 0.5\sigma$ has almost no chance of being released. On the other hand, a survey unit with a residual radioactivity that is at 50% of the $DCGL_W$, i.e., 0.5, is at the $DCGL_W - 0.5\sigma$, and has a 90 % chance of being released. If the sample size were nearer 100, the leftmost white curve shows that this probability would increase to about 99%. Thus, if the cost of remediation below a concentration of 0.5 was very high, the larger sample size might be chosen, but with the objective of achieving $\alpha = 0.10$ and $\beta = 0.01$.

A similar result is obtained for Scenario B, where a concentration of 1.5 = LBGR + 1.0σ. Figure 3.10 (second white curve from the right) shows that with $\alpha = 0.1$ and a sample size of 50, a survey unit with a concentration level of LBGR + 1.0σ has less than a 1% chance of being